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PCT/GB2005/000408



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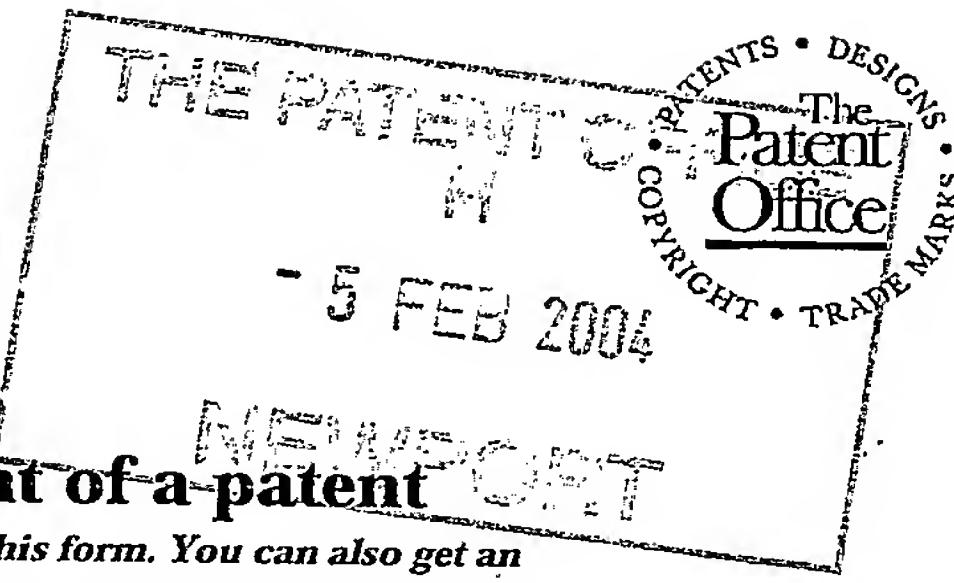
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1. Your reference

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2. Patent application number

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3. Full name, address and postcode of the or of each applicant (*underline all surnames*)

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4. Title of the invention

Improved Investment Casting Process

5. Name of your agent (*if you have one*)

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Patents ADP number (*if you know it*)

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IMPROVED INVESTMENT CASTING PROCESS

The present invention relates to an improved investment casting process, and in particular to a process which is much more rapid than conventional processes.

A typical investment casting process involves the production of engineering metal castings using an expendable pattern. The pattern is a complex blend of resin, filler and wax (or other vaporisable material such as expanded polystyrene) which is injected into a metal die under pressure. Several such patterns, once solidified are assembled into a cluster and mounted onto a wax runner system. The wax assembly is dipped into a refractory slurry consisting of a liquid binder and a refractory powder. After draining, grains of refractory stucco are deposited onto the damp surface to produce the primary refractory coating (the covering of the assembly with refractory material is known as "investing", hence the name for the process). When the primary coat has set (usually by air drying until the binder gels) the assembly is repeatedly dipped into a slurry and then stuccoed until the required thickness of mould shell is built up. Each coat is thoroughly hardened between dippings, and so each mould can take from between 24 and 72 hours to prepare. The purpose of the stucco is to minimise drying stresses in the coatings by presenting a number of distributed stress concentration centres which reduce the magnitude of any local stresses. Each stucco surface also provides a rough surface for keying in the next coating. The particle size of the stucco is increased as more coats are added to maintain maximum mould permeability and to provide bulk to the mould.

In recent years, advanced ceramics (e.g. silicon nitride) components have been developed which offer significant advantages over comparable metal components. Many processes by which such ceramic components can be made are known, and these include machining, injection moulding, slip casting, pressure casting and gelcasting. In gelcasting, a concentrated slurry of ceramic powder in a solution of organic monomer is poured into a mould and polymerised in situ to form a green body in the shape of the mould cavity. After demoulding, the green ceramic body is dried, machined if necessary, pyrolysed to remove binder and then sintered to full density. Aqueous based systems, such as the acrylamide system, have been developed in which water-soluble monomers are used, with water as the solvent.

It is an object of the present invention to provide an improved investment casting process which obviates or mitigates one or more problems associated with known investment casting processes and which preferably significantly reduces the time required for forming a shell mould.

According to the present invention, there is provided a process for the production of a shell mould, comprising the sequential steps of:-

- (i) dipping a preformed expendable pattern into a slurry of refractory particles and colloidal liquid binder whereby to form a coating layer on said pattern,
- (ii) depositing particles of refractory material onto said coating, and
- (iii) drying,

steps (i) to (iii) being repeated as often as required to produce a shell mould having the required number of coating layers, characterised in that during at least one performance of step (ii) the particles of refractory

material have been pre-mixed with a gel-forming material whereby to coat at least a portion of said refractory particles with said gel forming material such that after contact with the coating layer moisture is absorbed by the gel-forming material thereby causing gellation of the colloidal binder so reducing the time required for drying in step (iii).

Preferably, the method also includes the additional step (iv), carried out after the final step (iii) of applying a seal coat comprising a slurry of refractory particles and colloidal liquid binder, followed by drying.

In shell mould formation, the coating layer applied to the expendable pattern is usually referred to as the primary coating and subsequent slurry coatings are referred to as secondary coatings. Typically, three to twelve secondary coatings are applied.

Preferably, the gel-forming material-coated refractory particles are applied onto each secondary coating (i.e. during each repetition of step (ii) after the first). More preferably, the gel-forming material-coated refractory particles are applied onto the primary coating.

It will be understood that the deposition of refractory particles (coated or un-coated) in step (ii) may be achieved by any convenient method, such as by use of a rainfall sander or a fluidised bed.

Preferably, the amount of gel-forming material used in step (ii) is no more than 5wt% of the refractory material particles used in that step (ii), and more preferably no more than 2wt%. Preferred ranges are 2.5 to 5wt%, 1

to 2wt% and 0.2 to 1wt%. The preferred range may be dependent on the method used to form the coated refractory particles.

Preferably, said gel-forming material is a polymer, more preferably a super absorbent polymer exemplified by polyacrylamide and polyacrylate. A particularly preferred polymer is a sodium salt of a cross-linked polyacrylic acid (e.g. that sold under the tradename Liquiblock 144).

Preferably, the method includes a step of coating the refractory particles with the gel-forming material. This may be achieved by mixing the gel-forming material with water to form a gel and subsequently mixing the refractory particles into the gel followed by drying (e.g. at elevated temperature or using microwaves) and grinding the resultant mass.

Alternatively, the coating may be achieved by spray drying of the refractory particles, agglomeration or using a fluidised bed. Although the particle size of the polymer is not critical, where the coating of the refractory particles is achieved by first mixing the polymer in water, better dispersion is found with smaller particles (e.g. about 300 µm)

Advantageously, the process (apart from the use of the gel-forming material and the reduced drying times which result) can be substantially the same as a standard investment casting process using conventional machinery and materials. Thus, it will be understood that the nature of the expendable pattern, the slurry compositions used in step (i) (and step (iv) when present) and the refractory particles used in step (ii) may be any of those known to the person skilled in the art of investment casting.

Typical examples of refractory materials include, by way of example only, silica, zirconium silicate, alumino-silicates, alumina and yttria.

Moreover, the method preferably includes a step of removing the expendable pattern from the shell mould after the last step (iii) (or step (iv) when present) and more preferably the method includes a final step of firing the resultant shell mould.

Firing may be effected by heating to 950°C or more. Preferably however, a multi-step firing procedure is adopted. For example, a first step may involve heating to a temperature of from 400 to 700°C at a heating rate of from 1 to 5°C/min (preferably 1 to 3°C/min), followed by a second step of heating to at least 950°C (preferably about 1000°C) at a rate of from 5 to 10°C/min. The temperature may be maintained between the first and second steps for a short period (e.g. less than 10 minutes). Heating to at least 950°C may be effected in three or more steps.

The present invention further resides in a shell mould producible by the method of the present invention.

The present invention will be further described with reference to the following examples.

Comparative Example 1

This comparative example was intended to be representative of a prior art standard shell used for aluminium alloy casting and was constructed as follows:-

A filled-wax test piece was dipped into a first slurry (primary) for 30 seconds and drained for 60 seconds. Coarse-grained stucco material was

then deposited onto the wet slurry surface by the rain fall sand method (deposition height about 10cm). The coated test piece was placed on a drying carousel and dried for the required time under controlled conditions of low air movement. Extended drying removes moisture from the colloidal binder, forcing gellation of the particles to form a rigid gel.

Subsequent coats were applied by dipping (30 seconds) in a second (secondary) slurry followed by draining (60 seconds), with subsequent stucco application (rainfall sand method, deposition height about 10cm) and drying for the required time after each stucco application. In total, four secondary coatings were applied. Finally, a seal coat was applied (dip in secondary slurry, but no stucco application), followed by drying.

The primary and secondary slurry specifications are contained in Table 1, with the other various process parameters being given in Table 2. The latex addition in Table 1 relates to the use of a water-based latex system, which is added to the base binder to improve unfired strength.

Table 1: Slurry specifications for aluminium shell preparation
(all figures are wt %)

Slurry	binder silica content (wt%)	latex polymer addition (wt%)	filler type	refractory loading (wt% of total slurry)
Primary	26	6	(a) 200 mesh zircon (b) 200 mesh fused silica	77% a:b 3:1
Secondary	22	8	200 mesh fused silica	57%

Table 2: Shell build specifications for comparative example 1

Coating	Stucco	Drying air speed (ms ⁻¹)	Drying time (mins)
primary	50/80 mesh alumino-silicate	0.4	1440
secondary 1	30/80 mesh alumino-silicate	3	90
secondary 2	30/80 mesh alumino-silicate	3	90
secondary 3	30/80 mesh alumino-silicate	3	90
secondary 4	30/80 mesh alumino-silicate	3	90
seal coat	none	3	1440
		Total	3240

Comparative Example 2

The shell mould according to comparative example 2 was made in the same manner as for comparative example 1 using the slurries of Table 1, except that the stucco applied onto the primary and all the secondary coatings included particles of polyacrylate (at a loading of 1 part polyacrylamide to 40 parts stucco). The process parameters are given in Table 3. When the polyacrylate is deposited onto the wet slurry surface, it rapidly absorbs moisture from the adjacent colloidal portion of the slurry forcing gellation to a rigid gel without the necessity of extended drying times.

Table 3: Shell build specifications for comparative example 2

Coating	Stucco	Drying air speed (ms ⁻¹)	Drying time (mins)
primary	50/80 mesh alumino-silicate Liquiblock 144 (2.5wt%)*	0.4	10
secondary 1	50/80 mesh alumino-silicate Liquiblock 144 (2.5wt%)*	3	5
secondary 2	50/80 mesh alumino-silicate Liquiblock 144 (2.5wt%)*	3	5
secondary 3	50/80 mesh alumino-silicate Liquiblock 144 (2.5wt%)*	3	5
secondary 4	50/80 mesh alumino-silicate Liquiblock 144 (2.5wt%)*	3	5
seal coat	none	3	1080
		Total	1110

* polyacrylate having particle size < 300 µm

Example 1

A mixture of one part by weight of Liquiblock 144, 400 parts by weight of 50/80 mesh alumino-silicate and 400 parts by weight of deionised water was prepared and dried at 100°C for 24 hours with occasional mixing. Small samples were fired at 1000°C for 30 minutes and the percentage of polymer initially present determined by relating the percentage weight loss to burn-off of the polymer. Results indicated that the stucco contained 0.20% by weight of polymer. (The percentage of polymer is slightly less than the theoretical 0.25wt% since some water is retained in the stucco.)

As an alternative stucco preparation, the polymer was mixed vigorously with water to form a viscous gel. The refractory particles were then added and held in suspension within the gel matrix. Drying was effected in 20

minutes using a microwave and resulted in a dry solid block. The block was then carefully reground to prevent major changes in particle size. This method ensures that substantially all the refractory particles are coated with polymer.

Ceramic slurries were made up as shown in Table 1, and ceramic mould samples were dipped according to Table 4 below, the method being as used for comparative examples 1 and 2.

Table 4: Shell Build For Example 1

Coating	Stucco	Drying air speed (ms ⁻¹)	Drying time (mins)
primary	50/80 mesh alumino-silicate Liquiblock 144 (2.5wt%)*	0.4	10
secondary 1	50/80 mesh alumino-silicate Liquiblock 144 (2.5wt%)*	3	10
secondary 2	50/80 mesh alumino-silicate Liquiblock 144 (2.5wt%)*	3	10
secondary 3	50/80 mesh alumino-silicate Liquiblock 144 (2.5wt%)*	3	10
secondary 4	50/80 mesh alumino-silicate Liquiblock 144 (2.5wt%)*	3	10
seal coat	none	3	1080
		Total	1130

Shell Thickness Comparisons

Comparisons of the ceramic shell thickness achieved for comparative examples 1 and 2 and Example 1 shell systems can be seen in Table 5.

Table 5: shell thickness comparison

	status	Average Thickness (mm)	standard deviation (mm)
Comparative Example 1	unfired	4.99	0.39
	fired	4.81	0.56
Comparative Example 2	unfired	9.42	0.36
	fired	8.53	0.46
Example 1	unfired	6.41	0.42
	fired	6.75	0.56

Flat Bar Strength Measurement

Strength measurements were carried out in accordance with BS 1902. Injected wax bars were used as the formers for the ceramic shells formed by the procedures indicated above. After formation, the shells were steam Boilerclave (TM) de-waxed at 8 bar pressure for 4 minutes, followed by a controlled de-pressurisation cycle at 1 bar/minute. Test pieces, approximately 20mm x 80mm were cut using a grinding wheel and tested in a 3 point bend mode at room temperature (primary coat in compression).

A comparison of the maximum strengths achieved at room temperature in the 3-point bend mode for the shell samples is shown in Table 6. In addition to the green dry strength measurements, Example 1 and comparative examples 1 and 2 were tested for their green wet strength (to simulate strength during de-waxing) and their fired strength under different heating regimes. These results are also shown in Table 6 below.

Table 6: flat bar fracture strengths for Example 2

Example	Status	Fracture Strength (MPa)
Comparative Example 1	green, dry	4.86 +/- 0.54
	green, wet	4.55 +/- 0.47
	Fired (method A)	4.24 +/- 0.61
	Fired (method B)	3.80 +/- 0.38
Comparative Example 2	green, dry	2.80 +/- 0.75
	green, wet	1.63 +/- 0.36
	Fired (method B)	1.32 +/- 0.32
	Fired (method C)	0.98 +/- 0.29
Example 1	green, dry	2.11 +/- 0.16
	green, wet	1.29 +/- 0.16
	Fired (method B)	1.15 +/- 0.16
	Fired (method C)	1.18 +/- 0.09

Firing method A: to 1000°C @20C/min, dwell 60 min, furnace cool

Firing method B: to 700°C @ 1C/min, dwell 6 min, to 1000°C @5C/min, dwell 30 min, furnace cool

Firing method C: to 700°C @ 2C/min, dwell 6 min, to 1000°C @10C/min, dwell 60 min, furnace cool.

It should be noted that, as long as the fired strength is sufficient to hold the alloy being cast, lower shell strengths are actually advantageous for shell knock-out, particularly when casting relatively soft aluminium alloys.

Although the comparative example 2 shells were generally satisfactory, and can be produced much more quickly than the standard shells (comparative example 1), there was a tendency for the primary stucco coating to delaminate. On de-waxing and firing some cracking was also observed, although there was no metal breakout.

The de-lamination during shell manufacture and de-waxing may be due to the volume expansion of the individual polymer particles as water is absorbed and the particles 'swell'. Another observed effect, "stripping", may be due to the fact that the polymer is being introduced as a 'discrete' particle: not all the moisture from the slurry layer is being removed from the colloid phase as there will be a limit to the extent/rate of moisture transport through a capillary network. As the next layer is dipped, there will be an excess of moisture within the colloidal network, preventing gellation and catalysing 'breakdown' of the already gellated bonding structure. The expansion and cracking of the shell during firing is possibly due to a thermal mis-match between ceramic/colloid/polymer addition or expansion due to volatilisation of the polymer. Discrete particles will have a high concentration of polymer in one particular location leaving holes as this is removed.

In stark contrast, the Example 1 shells did not crack at all during de-waxing, with the entire shell (primary and secondary layers) remaining intact. After firing at the reduced heating rates (Methods B and C) the entire shell is whole with no observed delamination. The strengths are equivalent to the use of particle polymer additions but the fact that the entire shell remains intact means that the shells of the present invention will be superior for casting.





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